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ABSTRACT

This paper reviews the literature on handedness in infants and reaching behavior in neonates and speculates on evolutionary reasons for the development of handedness. Modern studies have reliably detected handedness from the second half of the first year of life. One study found a preference for the right hand in unimanual tasks at 6.7 months. Other studies have shown that contralateral reaching occurs 3 months sooner for the right hand than the left. Several studies of neonatal reaching behavior have shown that: (1) babies between 3 and 8 days old make predominantly right arm reaches to a visual target; (2) the right arm is spontaneously more active than the left in newborns; and (3) by 3 months of age, infants show greater persistence in grasping a rattle with the right hand than the left. Other studies have determined a correlation between neonatal head orientation preference, which begins to develop during the fetal stage, and hand preference. Evolutionary speculations on handedness concern the preference for cradling infants on the left arm; the fact that the infant must turn its head to pass through the birth canal; and the evidence from stone tools that Homo Erectus was predominantly right-handed. A list of 40 references is provided. (BC)

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Origins of handedness in human infants

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Abstract

It was established in the nineteenth century, through various baby biographies, that human infants show handedness. Species typical right hand dominance, can certainly be observed from the eighth month of life. However, there has been relatively little research on the origins of hand preference earlier in infancy. This paper reviews studies of the development of handedness in reaching and in hand-mouth coordination (both of which reveal population level right hand preferences from birth).The development of grasping later in the first year will also be considered as a source of evidence on handedness and bi-manual coordination. The relationship of "handedness" to "headedness" will be explored with respect to developmental evidence and in relation to some evolutionary speculations.

Introduction

The study of human infancy takes us straight to the heart of the the origins of handedness in human development . The species typical dominance of the right hand in a variety of motor tasks throughout the population can clearly be discerned quite early in the first year. Lauren Julian Harris (1982) in an extensive review of the history of research on infant handedness, points out that the question of the origins of handedness was of interest to a number of baby biographers in the 19th century. Darwin himself had noted incipient right handedness of his 77 day old son son Wiliam (Doddy) :

" When 77 days old he took the sucking bottle, (with which he was partly fed) in his right hand , whether he was held on the left or right arm of his nurse, and he would not take it with his left hand until a week later although I tried to make him do so; so that the right hand was in advance of the left" (Harris 1982 p 287) .

Harris notes that Doddy's right hand preference was only transient however and that the baby subsequently became left handed. Darwin put this down to heredity, since William's grandfather, mother and brother were also left handed. Darwin's brief observation touches on a number of topics which still preoccupy researchers today. When can we observe handedness in infancy? Is there any significance in the apparent inconsistency of early hand preferences , and how do factors such as the typical position in which babies are held, or their spontaneous postures in the womb or in early life, influence the development and expression of handedness?

Reasonably reliable Information on the onset of hand preferences in ontogeny has become available during the last 25 years. In addition, it has become possible to speculate on the origins of hand-preferences in phylogeny as research on the proto-hominids has become available. I will make use of a combination of these two sources of evidence in providing some clues about the origins of handedness in human development without meaning to imply any recapitulation of phylogeny in ontogeny,

When can we observe consistent hand preferences in infancy?

A simple way to define handedness is in relation to the preferred hand used for reaching. It was traditionally assumed that reaching begins at about three months, following a period of intensive inspection of the hand in the field of vision.

In recent years, however, it has become apparent that a form of visually elicited reaching can be observed in newborns. This is a ballistic reaching movement of the arm in the direction of a visual object, although it does not result in prehension. After the neonatal period there is regression in visually elicited reaching, with more coordinated movements beginning again from about 3 months. Now prehension does occur in association with reaching, but only after the hand comes into contact with the object. Between 3 and 6 months, the hands come under visual control and grasping starts to anticipate the size and shape of the objects. These developments are generally considered to apply to unimanual handedness, with left and right hands operating independently in ipsilateral visual space. Between 6 and 9 months, reaching and grasping becomes bilaterally coordinated with the hands adopting mutually complementary roles. Ramsay (1980) found that unimanual hand preference, measured at 7 months corresponded to the dominant hand for bimanual manipulation at 13 months. In bimanual tasks, the preferred hand takes the active role and the non-preferred hand an anchoring or supporting role, often with each hand adopting different grips in cooperative action. Grasping becomes increasingly differentiated, especially in the formation of the finely controlled finger grips certainly up to 14 months. Bimanual coordination actually continues to develop long after infancy but the main grip patterns, and their complementary use between the two hands are established by 18 months.

It would be as well to recognise that these stages are very broad approximations and that much normative research fails to consider biomechanical and ecological constraints which may conceal underlying competences. In recent studies some of the rate limiting factors on development have been revealed. For example, the French paediatric neuorologists Amiel Tisson and Grenier (1985) have shown well aimed reaching in babies of 3 weeks when the weight of the head is supported. Other apparently advanced postures can be sustained after extensive massage, which helps to bring about appropriate tonicity in postural systems of head and trunk. These are necessary conditions for control of the arms and expression of handedness. Newell (1986) has argued that such bodily constraints on action limit the movement patterns which may be observed , even though many aspects of motor coordination are actually present in the motor system. Other motor constraints important for the control of reaching and the expression of handedness include gaining voluntary control of the head and trunk. Task constraints are also

important, since factors such as the size and weight of objects to be grasped will influence the success of the action depending on whether objects are scaled to the strength and size of the infant's hands. Newell (1986) reports that a wider range of grips is available to the infant when such body scaling factors are taken into account, than was observed in the classic studies of Halverson (1931).

All of these ecological and biomechanical factors are rate limiting on the expression of handedness and on the development of motor skills. However, there are as yet no reports on handedness which have allowed for such constraints and so we must simply bear in mind that the norms in the classic motor development research almost certainly underestimate the infant's motor organisation, including the normative data on the origins of handedness.

Among the earliest systematic observations of handedness were those of Milicent Shinn (1894). She noted that once grasping had developed, toward the end of the fifth month, her niece showed a marked right hand preference in unimanual reaching tasks, which remained consistent thereafter. Right handedness was also expressed in later developing abilities, such as pointing or the fine tactile inspection of interesting objects with the index finger. Handedness seemed to emerge spontaneously, without any special training . Similar observations were made by other baby biographers, who sometimes noted that at 3 to 4 months, inconsistent hand preference or even consistent left handedness was expressed . Handedness usually settled to consistent right handedness from about the ninth month.

James Mark Baldwin (1890) carried out one of the first controlled studies of the origins of handedness with his own daughter, Helen. In a longitudinal series of 96 experiments ranging from the fifth to the end of the tenth month. An interesting object was presented to left , right or midline of the baby. Helen reached with her right hand 577 times , the left hand 568 and both hands 1042 times. Overall, Baldwin found no hand preference. However, during the eigth month he gave her a more difficult task, with the object just out of reach. Under these circumstances the right hand reached 74 times, the left 5 and both hands together only once. Helen would preferentially reach with the right hand, even when the object was presented to the left, across the midline. The increase in task difficulty revealed that Helen did have a hand -preference after all ! Baldwin described these aspects as "dynamogenic" factors. Baldwin had carefully controlled the early social and motor experience of the baby, who was never picked up in case this influenced her

expression of handedness. He concluded that handedness was determined by brain physiology, and not by habit, being carried or parental training.

The early studies, (reviewed by Harris (1982)) showed that species typical right handedness in the majority of babies is clearly observable by the 9th month. However, the definition of handedness is very broad and fails to distinguish between tasks, or between unimanual and bimanual hand preferences. Ramsay, (1985) has distinguished carefully between unimanual tasks, such as block banging and bimanual tasks such as dialling a toy telephone. A statistically significant unimanual preference for the right hand was found at an average age of 6.7 months and this coincided with the onset of duplicated syllable babbling, as in the sound baba. The unimanual preference then declined until there was no preference and reappeared four weeks later, and again 8 weeks later, on each occasion coincident with duplicated syllable babbling. A fluctuation in bimanual development between handedness and ambidextrality was observed at 14 months and again at 21 months, (Ramsay and McCune -Nicolich 1984). As with many other developmental phenomena, non-linear changes can be observed in the acquisition of handedness which may be related to hemispheric specialization and reorganization in motor control (see also McDonnell 1979). These changes may perhaps be related to the onset of speech.

Gaining precise control over the fingers seems also to be influenced by handedness , especially in the development of complementary power and precision grips. Verweij, Butterworth and Hopkins (in preparation) carried out a replication of Halverson's (1931) study of grip formation which confirmed the general developmental progression from hand to finger grasping in development. We found that reaching across the midline, into the contralateral space, occurs first for the right hand (at 11.3 months in our study) followed three months later by reaches with the left hand into the right side of space (at 14. 5 months). The majority of grips involved in contralateral reaching were the more precise finger grips. Infants were more likely to reach across the midline with the right hand than with the left (X 2.2 v 1.1 reaches per infant). For reaching to the ipsilateral side of space there was no difference in the total incidence of hand grasps or finger grasps between left and right hands ((L 45 hand, 92 finger (of which 23 pincer) R 42 hand, 98 finger (of which 27 pincer)). We did find that premature infants showed a different pattern and some delay in the development of finger grips, especially the pincer grip.

In someother studies, on the development of index finger pointing, a gesture known to be intimately associated with human communication which one might expect to be associated with laterality differences, we found that pointing occurs with either the right or the lef t hand. In our pilot study with 23 infants there was no significant difference in the likelihood of left or right hand points. However, the experimental situation favoured pointing with the left hand There was significantly more ipsilateral pointing than contralateral pointing, (Butterworth and Adamson-Macedo (1987). In another experiment , where the targets were equally distributed to left and right of the infant, right handed pointing predominated but again for targets ipsilateral to the pointing hand.(unpublished Butterworth and Franco).Young, Lock and Service (1985) also found, under conditions of semi-naturalistic observation, that right handed pointing was significantly more frequent thn left handed.

In summary, we can reliably detect handedness from the second half of the first year of life. It is probably a normal part of development for inconsistencies to be observed when periods of ambidextrality intersperse periods of strongly expressed laterality, both for unimanual and bimanual tasks. This is consistent with Gesell's description of reciprocal interweaving, in which fluctuations in handedness are associated with development of progressively more complex types of coordination between the hands. In species typical index finger pointing for referential communication the right hand dominates the left but there is no exclusive right side advantage .

Neonatal reaching

Classical studies of handedness tended not to begin until the so called "top level" reach develops at about five months. In recent years however, we have begun to look even earlier into the origins of handedness. We now have much more detailed information about the early phases of reaching and its differentiation during the early months. A report describing neonatal reaching by Bower (1972) was at first greeted with sceptical failures to replicate (DiFranco, Muir and Dodwell 1982). However, there are now studies which have confirmed Bower's observation of visually elicited reaching in newborns (eg Rader and Stern 1982) and in one study, data on newborn laterality is reported (Von Hofsten 1982) which showed that babies aged between 3 and 8 days made predominantly right arm reaches toward a visually presented target (417 R v 347 left; overall 11/14 babies R handed, 1/14 equal frequency, 2/14 L). A second study of 14 newborns by Von

Hofsten (1982) showed that 12/14 made predominantly right handed reaches to an oscillating target moving between 20cms from the left and 20 centimetres to the right of the midline (146 R v 86L).He was able to show that the accuracy of the approach path of the arm to the object was determined more by whether the baby was visually fixating the target than by the orentation of the infant's head. The predominant orientation of the head was to the midline, which suggests that right arm movements are in a majority, even when head orientation is neutral.

I have re-analysed data on neonatal reaching from an unpublished study (Butterworth 1982) in which babies of 1.7 days were presented with a bright red ping-pong ball at the midline. We measured spontaneous reaching movements (defined as arm extensions which included movement at the shoulder joint) during baseline control periods and when the object was present in the centre of the field of view. Spontaneous right arm movement dominated the left during the baseline period by a factor of two to one (X 7.3 L v 19.6 movements R) and a similar right arm preference was observed during the experimental period (X8.5L v 15.5 R). That is, the right arm is spontaneously more active in the newborn.These data on spontaneous movement, although unpublished, actually replicate an extensive study made in the 1930's which also showed greater spontaneous right arm motility in 100 newborns (Valentine and Wagner 1934, reported in Crowell 1967). It might be misleading to take this as evidence for innate handedness, since newborns make no attempt to grasp the visual object,. Thus, strictly speaking, lateral asymmetry of the hands may not be involved. Nevertheless, the evidence is consistent with an innate asymmetry, with weak right dominance, in the control of reaching.

A more direct measure of hand asymmetries in the newborn makes use of the innate grasping reflex. Harris (1982) cites a spectacular study of strength of grip in newborns by the behaviourists Watson and Raynor (1921) They found no difference in the duration with which babies aged between 1 and 21 days could suspend their own weight by left or right hands, which suggests that strength of reflexive grasping is similar between the hands. Caplan and Kinsbourne (1976) found that by 2.7 months, 13/21 infants showed greater persistence in grasping an interesting rattle with the right hand, 4/21 with the left hand and 4/21 showed no difference in duration of grasping between the hands. Petrie and Peters (1980) also found a right handed advantage in duration of grasping when a single rattle was presented. However, when both hands were occupied simultaneously, there

was no difference in the duration of grasping. That is, there are innate differences in handedness, as measured by duration of grasping but their expression depends on other factors, as yet unspecified, such as deployment of attention. It seems possible that hand laterality differences may be revealed in voluntary grasping and concealed by reflexive grasping, but this is just speculation.

Gesell and Ames (1947) first suggested that the direction of baby's spontaneous head orientation preference predicts handedness. They measured the direction which babies placed their heads, aged 6 -8 weeks in the asymmetric tonic neck reflex (ATNR) posture Seven infants with right head ATNR were all right handed at 10 years, whereas 9 infants with left headed ATNR were equally divided by handedness at 10 years (5 R and 4L). Cioni and Pellegrinetti (1982) studied head position preferences in 70 newborns with right handed parents and siblings and 19 newborns with at least one left handed parent or sibling. The first group showed a marked right head position preference, and were statistically significantly more likely to turn to the right than the left when the head was released from the midline position (R41, L24, O 5). The latter group showed no asymmetry (R 7, L 7 , O 5). Forced rotation of the head was unsuccessful in attempts to elicit the ATNR. The authors suggest that a genetic basis must at least in part be responsible for the asymmetry in spontaneous head position preference.

Another measure of hand dominance may be obtained from studies of hand-mouth coordination in the newborn. Butterworth and Hopkins (1988) and Hopkins et al (1988) carried out extensive investigations of this motor synergy. Newborn infants when placed supine will spontaneously turn the head to one side, usually the right and make spontaneous arm movements which often contact the mouth. The mouth itself opens before the hand starts to move, as if anticipating the arrival of the hand. Significantly more hand movements were made ipsilateral to the orientation of the head than contralateral to it. Mouth contact was also significantly associated with ipsilateral hand movements. The majority of hand movements to the mouth in both these studies were right handed.The hand-mouth movements showed a regression during the first three months and return with the dominant hand contacting the mouth with the head held at the midline. Hand-mouth contacting with the head held at the midline is significantly correlated with the degree of postural control over the head. (Hopkins et al 1990). These data suggest therefore that there is a relationship between direction of head orientation preference and laterality in hand-mouth contacting, with the preferred rightward

head orientation undergoing a progressive realignment to the midline. The innate head right position preference is significantly more lateralized than it will be subsequently and the normal,head midline posture starts to be apparent from about the 6th postnatalweek.It is extremely interesting to note that the head orientation preference appears in the fetus at the 38th week of gestation, as if in anticipation of birth. The change in posture of the head to the right occurs before the head is engaged with the birth canal. Until the 36th gestational week the preferred fetal head orientation is to the midline, interspersed with fewer, equally distributed head left and head right postures (Ververs, deVries, Geijn and Hopkins 1992).

The persistent, neonatal head orientation preference to the right seems therefore to be a transitory phase bridging pre-natal and post-natal life. Hand mouth contacting, however occurs up to 100 times per hour from the twelth week of gestation. It is not known whether there may be lateral asymmetries in fetuses in hand- mouth movements . If so, this may reverse the theoretical link between headedness and handedness suggested by Michel (1981) and Gesell and Ames (1947), in favour of a more fundamental asymmetry common to head and hand arising in embryogenesis (Wada and Davis 1977).

A number of explanations for the postnatal association between newborn head position preference and handedness have been offered, including the suggestion that it provides an extended opportunity in the early weeks of life to view the hand, which may consolidate eye hand coordination. Since congenitally blind infants are also predominantly right handed, it seems unlikely that visual regard of the hand can be responsible for hand dominance. Another possibility is that the head orientation preference, through its influence on hand-mouth coordination, may "tune up" the reaching system. Rochat (1989) showed that when babies aged 6 months are given support at the trunk, their natural tendency is to reach unilaterally toward an object to bring it to the mouth. He suggests that unilateral handedness may emerge through the complementary roles of the arms ensuring balance while reaching, with the dominant hand moving forward to grasp the object and the non-dominant arm moving backwards as a counterbalance. On this view, headedness may be related to handedness via the intermediary of oral grasping. Hand mouth coordination may provide an apprenticeship in targeted reaching which provides a developmental substrate for subsequent visually guided reaching and this in turn takes over right hand

dominance.

Evolutionary Influences

Finally, perhaps we may be permitted to make some evolutionary speculations on the origins of handedness. This train of thought was triggered by the observation, now well substantiated for humans, that there is a preference to cradle newborns on the left arm (Harris and Fitzgerald 1982). This preference for left arm cradling, ranging upwards of 60% to 75% of cases occurs in nulliparous females , in males and even among female pre-schoolers lifting a doll (Saling and Tyson 1981, Saling and Bonnert (1983). The most well known explanation is Salk's (1973) hypothesis that the typical holding posture enables the infant to benefit from the soothing sound of the mother's heart beat. I should like to suggest another hypothesis more closely connected with the importance of face to face contact for pre-verbal communication. Given the predominant right headed preference of the newborn, carrying on the left arm would maximise the opportunity for face to face contact from birth onwards.As Papousek (1991) has stressed, a fundamental reason for cerebral asymmetry is the evolution of speech. He argues that communication is the primary evolutionary driver and handedness is the secondary by-product. Of course, it is possible that both communication and tool use have co-evolved, and that both make use of the same manual specialisation (Butterworth and Franco 1992).

The head orientation preference in turn, seems likely to be preparatory to the passage through the birth canal, which necessitates the baby flexing and rotating its head to one side to enable passage through the asymmetric pelvic girdle, (although this alone cannot explain why the population preference should be for the right and not the left).. The structure of the pelvic girdle is thought to be a specific adaptation to the upright walking posture with further modifications for obstetric reasons.

The oldest fossil hominid is the Australopthicene Lucy, at approximately 3.8 million years. She had the upright posture and feet which left footprints comparable to modern man.There is some controvery over whether her pelvic girdle would have necessitated rotation of the fetus through the birth canal, although Berge and Orban -Segebarth and Schmid (1984) suggest that head flexion would have been necessary. Her hands however were intermediate between a contemporary human and a chimpanzee, with a smaller range of possible power and precision grips

especially the fully abducted pincer grip. We do not know whether the early Australopithicenes showed handedness but by about 1.8 million years ago, the hand of Homo erectus approximated its modern form. Stone tools in the fossil record and analyses of their manufacture, suggest that the majority of their users were right handed (Toth 1985).

The question is "If headedness and handedness reveal a deeper, underlying cause of asymmettry in genetics and embryogenesis, how did these factors originate in phylogeny? It is possible that headedness, as revealed by the anatomy of the pelvis of Lucy, preceded handedness or both right headedness and right handedness may have been coincident in evolution . It seems likely that unravelling the complex of factors underlying handedness, tool use, preferential carrying patterns, face to face communication and the obstetric consequences of the upright posture will give a deeper, evolutionarily based understanding of the ultimate origins of human handedness. In the meantime, perhaps I may be permitted to speculate on what may be one of the main implications of handedness for developmental disorders. It could be that those functions most recently evolved, such as the fine control of the hand in tool use and communication, will be those most susceptible to developmental anomalies. Aspects of lateralised manual functioning such as the pincer grip or its corollary manual pointing, precise tool use and language, seem particularly vulnerable to developmental disorders. Perhaps knowing more about the origins of handedness in both ontogeny and phylogeny will help us to a better understanding of what happens when development is disordered.

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